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METHODS FOR MEASURING THE AIR HEATER LEAKAGE IN A COAL FIRED THERMAL GENERATING STATION

Report No 89-98-K

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ABSTRACT

The tracer gas technique can be used to measure the air leakage to the flue gas in the air heater of a coal fired thermal generating station but the results must be verified if poor mixing is encountered. Because there is no possibility of direct measurement through conventional instrumentation, an indirect method is needed. Two methods, one based on the carbon dioxide balance and the other based on the oxygen balance were developed in this work to meet the need. Compared to the tracer gas technique the new methods employed no external tracer gas thus there is less of a mixing problem. They are especially useful to compare the test results of one method with that of others to improve the confidence of the findings.

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31-570-071	837.241	May 30, 1989	89-98-K



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EXECUTIVE SUMMARY

METHOD FOR MEASURING THE AIR HEATER LEAKAGE IN A COAL FIRED THERMAL GENERATING STATION

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A recent gas flow study using a tracer gas technique at Lambton TGS found that about 25.5% of the air intake cross flowed to the flue gas in air heater A of Unit 4 boiler. This large fraction of air entering at 28°C and discharging at 145-160°C, by-passing the boiler, results in losses of heat to the stack. Confirmation of this leakage is important in making the decision to take remedial action. It is needed, therefore, to find a convenient alternative capable of verifying the result obtained by the tracer gas technique. Two methods, one derived from the oxygen balance and the other derived from the carbon dioxide balance were developed in this work for meeting the need. These two methods in addition to the tracer gas technique are summarized in this report.

The tracer gas technique has been used for flow measurement in the chemical industry and for testing ventilation systems by building engineers with good results. The tracer gas method was employed successfully in the UK also for power plant testing. Our application to Lambton TGS also was considered successful, however, the mixing and dispersion of tracer gas into the gas stream seemed more difficult than expected. The results must be verified.

The methods developed in this work using a carbon dioxide balance and also an oxygen balance are similar to the tracer gas technique but they need no external tracer gas. Instead, the existing internal components are used as the tracer, thus, less mixing or dispersion problems exist. These two methods can be used independently or for checking the result of the SF₆ tracer gas method.



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To: Dr. D. Mills
Director of Research

METHODS FOR MEASURING THE AIR HEATER LEAKAGE IN A COAL FIRED POWER GENERATION STATION

1.0 INTRODUCTION

A recent gas flow study using a tracer gas technique at Lambton TGS (OHRD Report 88-232-H) found that about 25.5% of air intake cross flowed to the flue gas in air heater A of unit 4 boiler. This large fraction of air entering at 28°C and discharging at 145-160°C, by-passing the boiler, results in loss of heat to the stack. Confirmation of this leakage is important in making the decision to take remedial action. It is needed, therefore, to find a convenient alternative capable of verifying the result obtained by the tracer gas technique. Two methods, one derived from the oxygen balance and the other derived from the carbon dioxide balance were developed in this work for meeting the need. These two methods in addition to the tracer gas technique are summarized and discussed in this report.

2.0 TRACER GAS METHOD

If a tracer gas such as sulphur hexafluoride is injected into the air upstream of the respective FD fan, the tracer gas will mix with the air and the mixing will be enhanced by the fan before the gas enters the air heater. That part of the tracer carried by the air to the boiler will be destroyed while the other part of the tracer leaked with air to the flue gas can be detected anywhere along the flue gas duct downstream of the air heater, conveniently, at all ID fan discharges. If tracer gas is injected at locations b, c or d as shown in the schematic diagram of the Lambton TGS boiler, Figure 1, the tracer leaked with air can be detected at locations m and n.

Following the notations as specified in Figure 1 and the material balances of the tracer gas, the following equations hold:

$$L_{sn}/A_{sn} = (G \& L_m \cdot X_m + G \& L_n \cdot X_n) / I_b \quad (1)$$

$$L_{ss}/A_{ss} = (G \& L_m \cdot X_m + G \& L_n \cdot X_n) / I_d \quad (2)$$

$$L_p/A_p = (G \& L_m \cdot X_m + G \& L_n \cdot X_n) / I_c \quad (3)$$

From these equations the air leakage to flue gas rate to the air intake flowrate mole ratio for each air heater can be calculated. This method was employed in the recent study for Lambton TGS where an air leakage equivalent to 25.5% of the intake air flowrate was found.

3.0 CARBON DIOXIDE BALANCE METHOD

Figure 2 depicts a simplified flow diagram of a boiler and a heater assembly where the flow streams also are labelled. From a material balance of the carbon dioxide in the flue gas the following equation holds:

$$G X_1 = (G + L)X_2 \quad (4)$$

where X_1 , X_2 represent the CO_2 concentration in flue gas at the air heater inlet and outlet, respectively. In this formulation the CO_2 level in air about 350 ppm is neglected.

As defined in Appendix 1 the flue gas to air ratio, R , which is a function of coal composition and excess air level can be related by

$$G = R(A-L) \quad (5)$$

From Equations (4) and (5), Equation (6) can be derived.

$$L/A = 1/(1 + (1/R)(1/(X_1/X_2 - 1))) \quad (6)$$

Thus, the mole ratio (air leakage to flue gas/air intake) can be calculated.

In this equation the carbon dioxide concentration X_1 and X_2 can be obtained from flue gas sampling and analysis and the R -value can be calculated from data of the coal ultimate analysis and data of the excess air. The excess air, in turn, can be calculated from the oxygen concentration in the flue gas. The method of calculation is described in Appendix 1.

4.0 OXYGEN BALANCE METHOD

In Figure 2 if X_1 and X_2 are changed to represent oxygen concentration in flue gas at the air heater inlet and outlet respectively and X_0 is to represent the oxygen reference concentration in air the following relation holds:

$$GX_1 + LX_0 = (G + L)X_2 \quad (7)$$

Combining this equation with Equation 5 results in Equation (8),

$$L/A = 1/(1 + ((X_0 - X_2)/(X_2 - X_1))/R) \quad (8)$$

Again, this equation can be used to calculate the mole ratio (air leakage to flue gas/air intake) in an air heater.

5.0 APPLICATIONS

5.1 Flue Gas Compositions

Using formulae developed in Appendix 1 and data obtained in Appendix 2 based on the information of the reference coal, the oxygen and carbon dioxide contents in the flue gas can be calculated using % excess air as the parameter. The results so obtained are shown in Figure 3.

It may be seen that should 7.7 mol % O_2 be measured in the flue gas the excess air would be 60 mol % and the CO_2 would be 10.6 mol %.

Should 3.5 mol % O_2 be present in the flue gas the excess air would be 21 mol % and carbon dioxide would be 14 mol %.

5.2 Flue Gas to Air Mole Ratio, R

Similarly from information taken from Appendix 2, the flue gas to air intake ratio, can be constructed, Figure 4. It may be seen that this ratio is not very sensitive to the excess air changes; the ratio drops from 1.053 to 1.036 as excess air increase from 0 to 50%.

5.3 Air Heater Leakage

Assume that oxygen in the flue gas at the heater inlet and outlet are respectively 3.5 and 7.7 mol % or

$$(X_o - X_j) / (X_j - X_i) = (0.21 - 0.077) / (0.077 - 0.035) = 3.17$$

Excess air at $X_i = 0.35$ is 21.0 mol %.

From Fig 4 the flue gas to air mole ratio is 1.044.

Substitute these information into Equation (8),

$$L/A = 1 / (1 + 3.17 / 1.044) = 0.25$$

Under the same conditions the corresponding carbon dioxide concentrations can be obtained from Figure 3, namely,

$$X_i = 14.0 \text{ mol \%}$$

$$X_j = 10.6 \text{ mol \%}$$

$$\text{Therefore, } X_i/X_j = 14.0/10.6 = 1.32$$

with $R = 1.044$, Equation (6) becomes

$$L/A = 1 / (1 + (1/1.044)(1/(1.32 - 1))) = 0.25$$

Both methods, that of oxygen balance or that of carbon dioxide balance, give identical results.

Again, using the reference coal analysis quoted in Appendix 1 and using excess air as the parameter Equations (6) and (8) can be converted into graphs in Figures (5) and (6) respectively.

It may be seen that the air leakage calculations are quite sensitive to changes of either carbon dioxide or oxygen concentration but it is insensitive to the changes of excess air level.

A one percent change in each of the oxygen and CO₂ level would affect the excess air calculation (including air heater leakage) by about 7% and 10% respectively (Figure 3). A change of oxygen from 3.5 to 4.5% would change the L/A mole ratio from 0.175 to 0.225, a change of CO₂ from 14 to 13% at the heater inlet would change the L/A mole ratio from 0.25 to 0.195 in the above sample calculations.

6.0 DISCUSSION

6.1

The tracer gas technique has been used for flow measurements by the chemical industry and for testing ventilation systems by the building industry with good results. This technique was employed successfully in UK also for power plant testing. Our recent application to Lambton TGS also was considered successful, however, the mixing of tracer gas with flowing fluid seems more difficult than expected. The impact of this mixing problem is quite difficult to estimate unless an independent check is available to verify the results especially for the air heater leakage which cannot be measured directly by the conventional instrumentation.

6.2

Methods developed in this work using CO₂ and O₂ balances are similar to the tracer gas technique; no external tracer, but an internal tracer is used. Therefore, there would be less of a mixing problem. These methods can be used independently for measuring air heater leakage or for checking the result obtained by the tracer gas method.

6.3

Both calculated O₂ and CO₂ composition changes are quite sensitive to changes of excess air levels including air leakages. Therefore, O₂ and CO₂ are good built in tracer gases for calculating the air heater leakage.

6.4

ASME Air Heater Performance Test Code, PTC 4.3-1968, also includes the CO₂ concentration ratio in their formula,

$$L/A = (X_i - X_j)/X_j \times 90\%$$

It may be recognized that this formula is only an approximation to Equation 6.

6.5

The unburnt (residue) carbon in ash normally is small and can be neglected for simplicity. Should it be large due to special circumstances it could be included as the residue carbon term indicated in Equations A2, A11 and A17 for accuracy.

6.6

Most flue gas properties and compositions can be calculated from coal ultimate analysis and oxygen content in the flue gas as detailed in Appendix 1. Oxygen and carbon dioxide monitoring at proper locations would provide good information for plant performance evaluation.

7.0 CONCLUSIONS

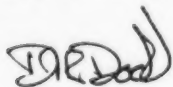
7.1

Three methods for measuring the air heater leakage discussed in this work can be used either independently or supplementally using one result to verify the others with confidence.

7.2

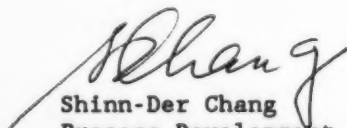
Most flue gas properties and compositions can conveniently be calculated from data of coal ultimate analysis and data of oxygen content in the flue gas. This information is normally available or can be obtained easily from thermal generating stations.

Approved by:



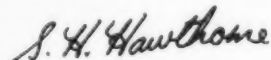
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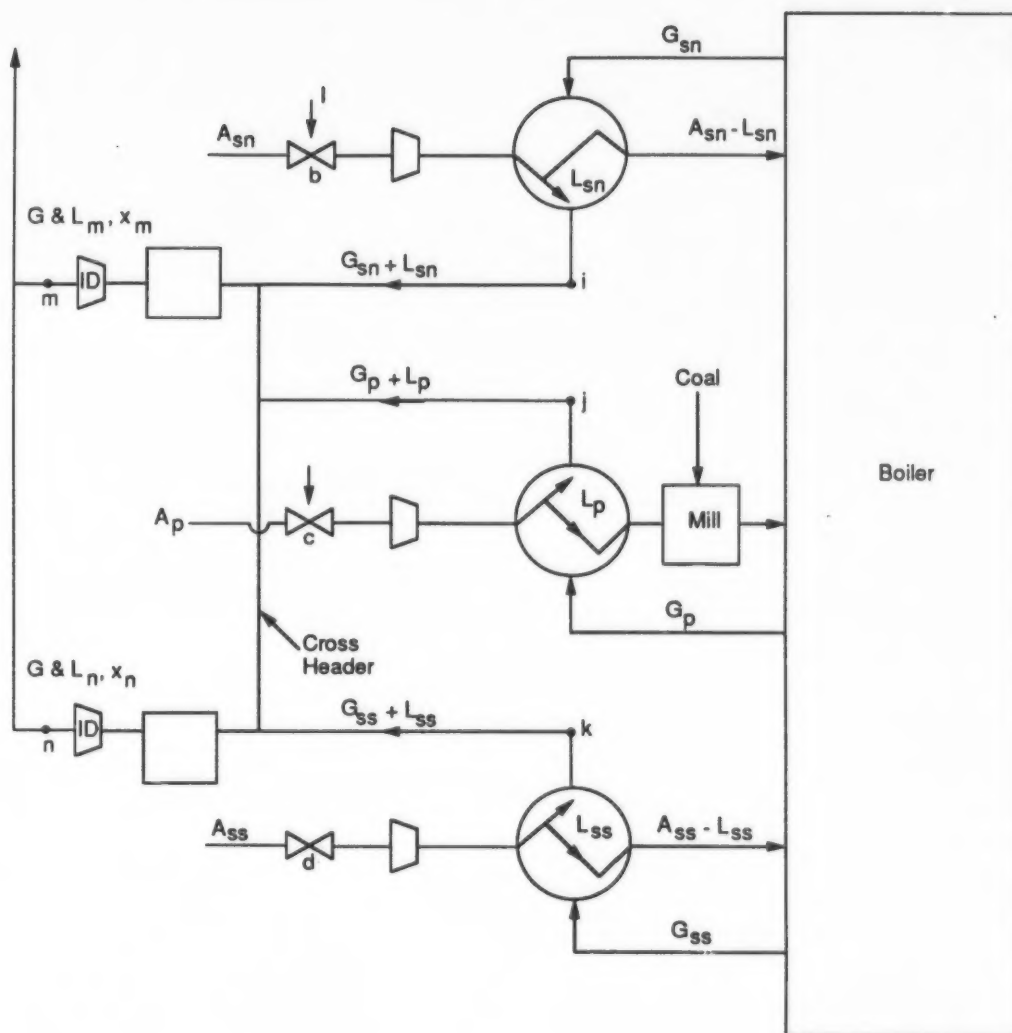


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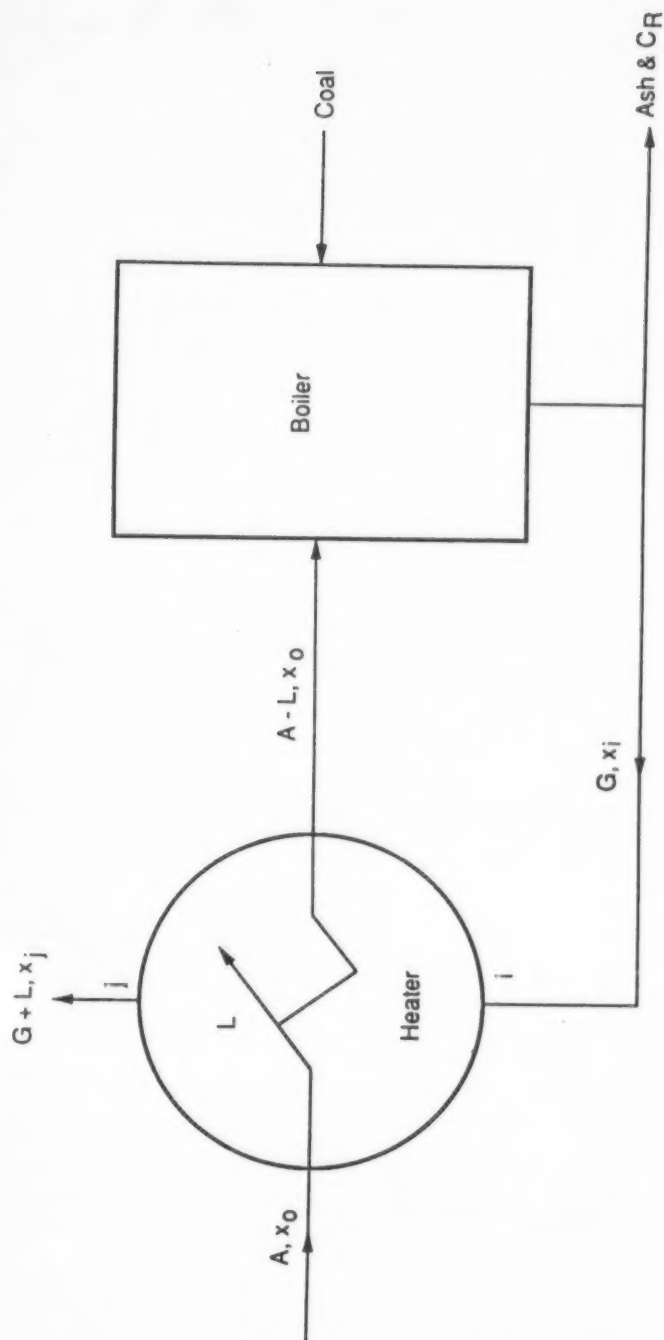
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A, Air Flowrate
 G, Flue Gas Flowrate
 I, Trace Gas Injection Rate
 L, Air Leakage Rate (air cross flow to flue gas)
 G & L, Flue Gas Flowrate Air Leakage Included
 x, Tracer Gas Concentration

Subscripts:
 sn, Secondary air North Side
 p, Primary Air
 ss, Secondary Air South Side
 b, c, d, i, j, m, n
 Locations as Marked

FIGURE 1
SCHEMATIC DIAGRAM LAMBTON TGS BOILER



A = Air, in kmol/h
 L = Air Leakage, kmol/h
 G = Flue Gas, kmol/h
 CR = Residue (Unburnt) Carbon
 x = Concentration of CO_2 or O_2 in the Flow Streams

Subscripts = Locations

FIGURE 2
SIMPLIFIED BOILER AND AIR HEATER ASSEMBLY

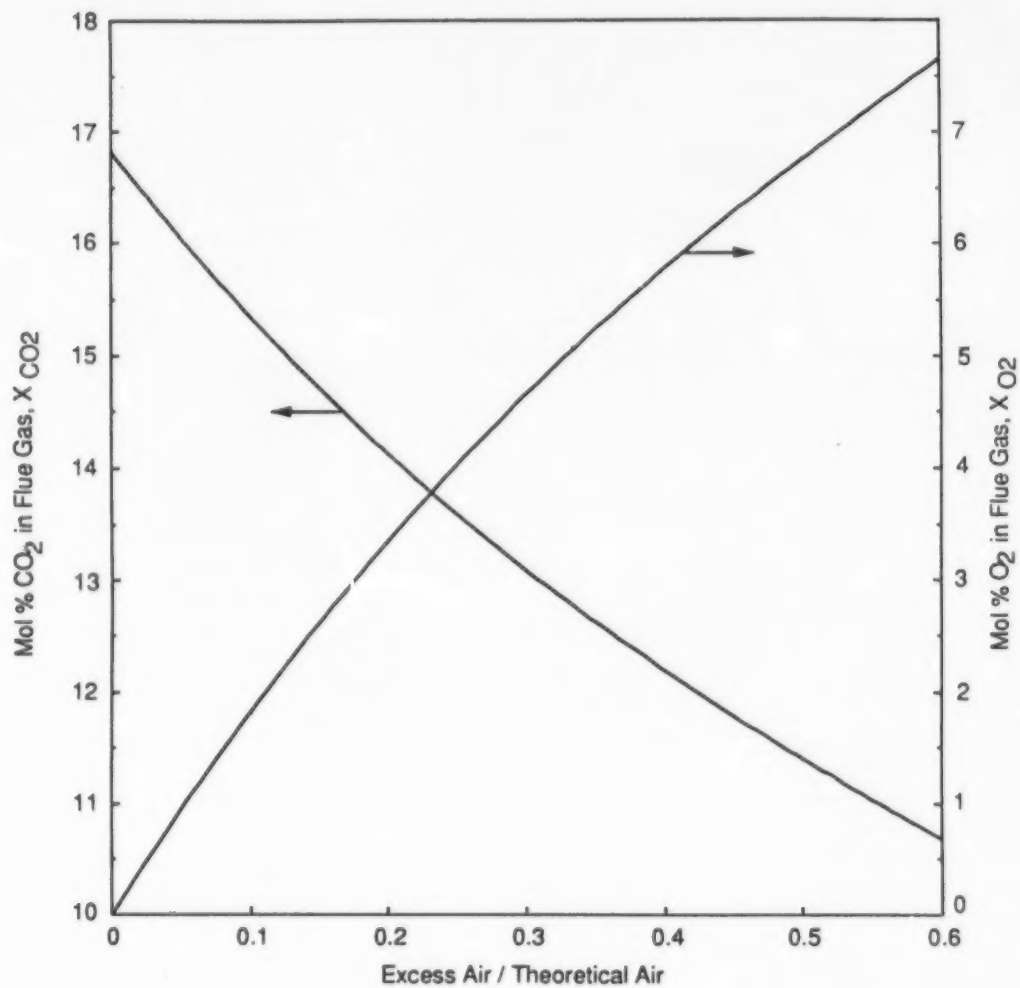


FIGURE 3
FLUE GAS COMPOSITIONS CALCULATED
BASED ON THE REFERENCE COAL
APPENDIX 1 IN TERMS OF EXCESS AIR

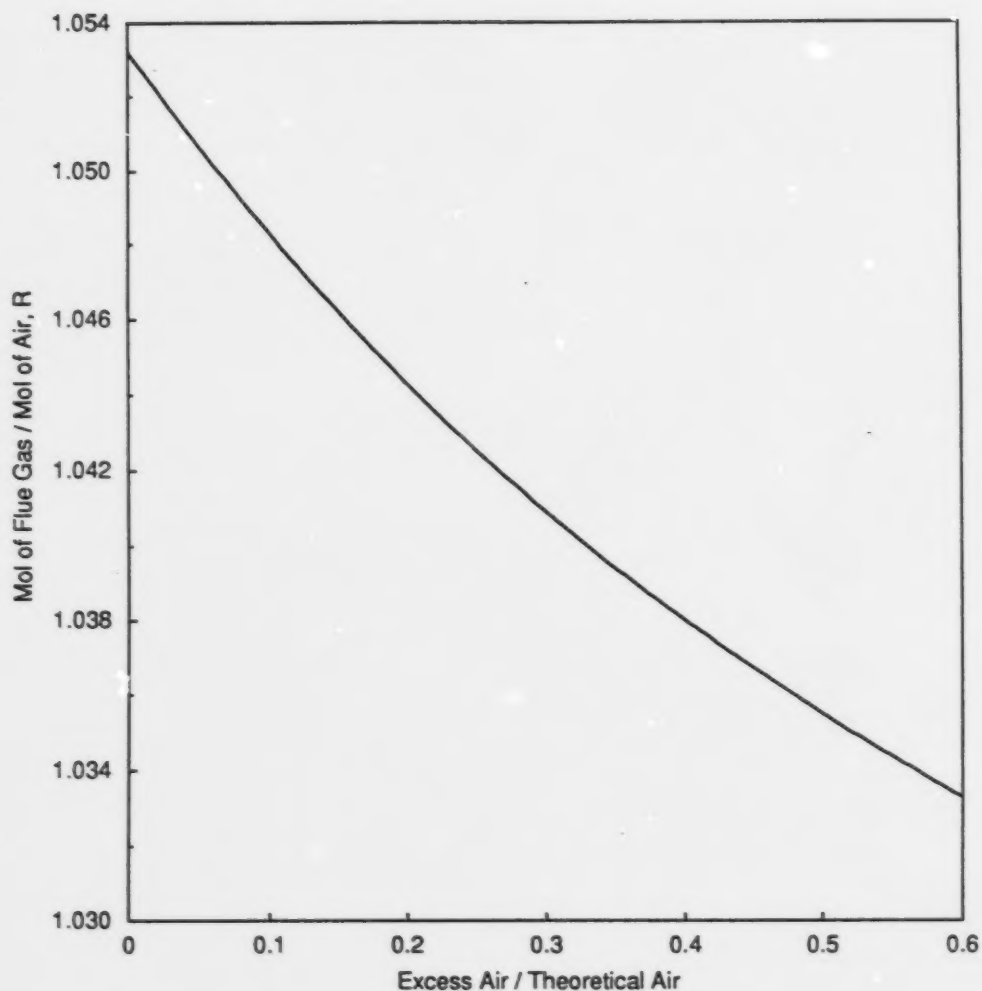


FIGURE 4
MOL OF FLUE GAS TO MOL OF AIR BASED ON
THE REFERENCE COAL APPENDIX 1
IN TERMS OF EXCESS AIR

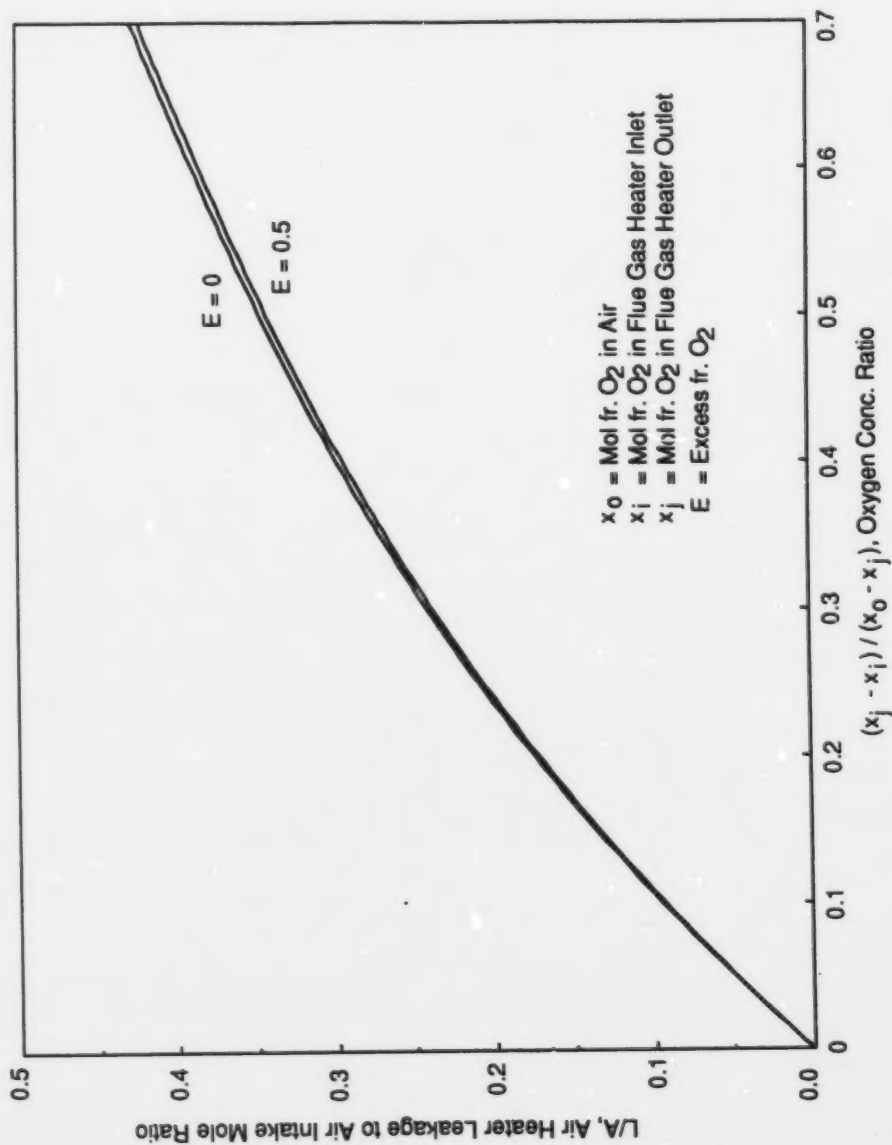


FIGURE 5
AIR HEATER LEAKAGE FROM OXYGEN
BALANCE USING EXCESS AIR AS THE PARAMETER

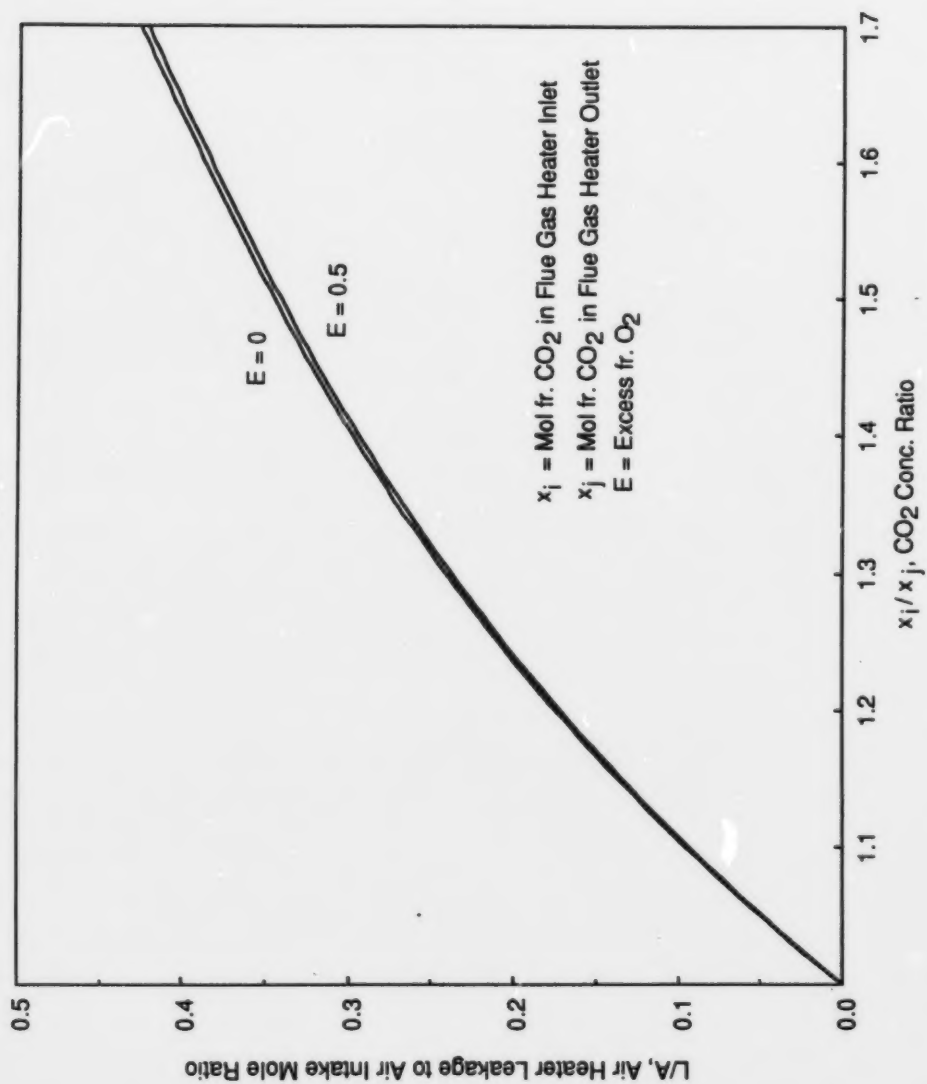


FIGURE 6
 AIR HEATER LEAKAGE FROM CARBON DIOXIDE
 BALANCE USING EXCESS AIR AS THE PARAMETER

APPENDIX 1

Calculation of Flue Gas Properties from Coal Ultimate Analysis and Oxygen Content in the Flue Gas

Define:

- X_o - mole fraction of oxygen in air
 X - mole fraction of oxygen in flue gas
 C_R - % residue (unburnt) carbon
 T - theoretical oxygen requirement, K mol O_2 /100 kg fuel
 $\quad - \% (C - C_R)/12 + \% H/4 + \% S/32 - \% O/32$ (1)
 g_o - theoretical flue gas expected with theoretical oxygen supply, K mol/100 kg fuel
 $\quad - \% (C - C_R)/12 + \% H/2 + \% S/32 + \% H_2O/18 + \% N/28 + \% Cl/35/2 + \% F/19/2$ (2)

Excess Air

By definitions:

Theoretical air, K mol/100 kg fuel
= T/X_o

$$\text{Flue gas, K mol/100 kg fuel,} \quad (3)$$

$$g = g_0 + T(1 - X_0)/X_0 + ET/X_0 \quad (4)$$

where E is the fraction of excess air over that of theoretical.

Excess oxygen, X, mole fraction

$$X = ET / (g_0 + T(1 - X_0) / X_0 + ET / X_0) \quad (5)$$

This equation can be rearranged into

$$\text{Excess air} = 100E = 100X (g_o/T + 1/X_o - 1)/(1 - X/X_o) \quad (6)$$

Flue Gas to Air Ratio

By definitions:

$$\text{Total air supply} = (1 + E) (T/X_n) \quad (7)$$

Combining this equation with Equation 4 the flue gas to air ratio, R , mol/mol, can be expressed:

$$R = (g_0 + T(1 + E)/X_0 - T)/(T(1 + E)/X_0) \quad (8)$$

or simplified to

$$R = 1 + (g_0/T - 1) X_0/(1 + E) \quad (9)$$

Molecular Weight

If molecular weight of air can be expressed by the formula

$$32 X_o + 28(1 - X_o) \quad (10)$$

together with the total air supply as expressed in Equation 7 and the total flue gas flow as expressed in Equation 4 the molecular weight of flue gas can then be formulated as follows.

$$MW = (100 - \% \text{ Ash (carbon free)} - \% C_R + (1 + E)(T/X_o)/(32 X_o + 28(1 - X_o)))/(g_o + T(1 - X_o)/X_o \text{ ET}/X_o) \quad (11)$$

Compositions

Define:

M = moisture generated, k mol/100 kg fuel
= $\% \text{ H}/2 + \% \text{ H}_2\text{O}/18 - \% \text{ Cl}/35/2 - \% \text{ F}/19/2$

Thus, moisture content in mol/mol of flue gas

$$X_{\text{H}_2\text{O}} = M/g \quad (12)$$

Similarly,

$$X_{\text{N}_2} = (\% \text{ N}/28 + (1 + E)(T/X_o)(1 - X_o))/g \quad (13)$$

$$X_{\text{SO}_2} = \% \text{ S}/32/g \quad (14)$$

$$X_{\text{HCl}} = \% \text{ Cl}/35/g \quad (15)$$

$$X_{\text{HF}} = \% \text{ F}/19/g \quad (16)$$

$$X_{\text{CO}_2} = \% (\text{C} - C_R)/12/g \quad (17)$$

$$X_{\text{O}_2} = \text{ET}/g \quad (18)$$

APPENDIX 2

Sample calculations of Flue Gas Properties from Coal Ultimate Analysis and Oxygen Content in the Flue Gas

Ultimate Analysis of Coal

(Reference coal for flue gas desulfurization plant design)

<u>Components</u>	<u>kg/kg</u>
C	0.674
H	0.04512
N	0.01222
S	0.03
O	0.05735
ash (carbon free)	0.12
H ₂ O	0.06
Cl	0.0012
F	0.0007

Heating value 28610 KJ/kg

Firing rate design, 184 Mg/h/unit
100 % MCR, 160.6 Mg/h/unit

$$g_o = \% C/12 + \% H/2 + \% S/32 + \% H_2O/18 \\ + \% N/28 + \% Cl/17.5 + \% F/9.5 \\ - 8.3470$$

$$T = \% C/12 + \% H/4 + \% S/12 - \% O/32 \\ - 6.6592$$

$$M = \% H/2 + \% H_2O/18 - \% Cl/35.2 - \% F/19.2 \\ - 2.5751$$

$$E = g_o + T(1 - X_o)/X_o + ET/X_o \\ - 33.398 + 31.7104 E$$

From these values and equations in Appendix 1 the following table can be constructed using excess air, E, as the parameter.

E	0	.1	.2	.3	.4	.5
g	33.40	36.57	39.74	42.910	46.08	49.25
$X_{SO_2} \bullet E6$	2807	2564	2358	2185	2035	1904
X_{H_2O}	7.74	7.07	6.51	6.02	5.61	5.25
X_{N_2}	75.13	75.47	75.75	75.98	76.21	76.39
X_{CO_2}	16.82	15.36	14.13	13.08	12.19	11.40
X_{O_2}	0	1.82	3.36	4.66	5.78	6.76
$X_{HCl} \bullet E6$	103	93.5	86.3	79.9	74.4	69.7
$X_{HF} \bullet E6$	110	100	92.7	85.8	79.9	74.8
molecular weight	30.02	29.91	29.83	29.75	29.70	29.64
R	1.0532	1.0484	1.0443	1.0409	1.0380	1.0355